Surface Resistivity Measurements for Quality Assurance Pave the Way to Savings in Louisiana

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The permeability of the concrete determines whether a structure will have a long service life free from corrosion of the structural steel. Concrete permeability depends on the ratio of water to cementitious materials (w/cm), total cementitious content, aggregate gradation, and the amount of supplementary cementitious materials (SCMs) in the mix.

Many engineers rely on the permeability specifications for portland cement concrete pavements and structures to ensure long service life. Most prefer the Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (ASTM C1202). Until recently, this was the only test that quickly determined the resistance of concrete to chloride ion penetration. Surface resistivity measurements, however, have advanced and can generate rapid results for chloride permeability. Florida, for example, allows the use of a surface resistivity device that correlates well with rapid results for chloride permeability as one step in the acceptance of a concrete mix design.

The surface resistivity device has four pegs. A current is applied across the outside pegs and the potential resistivity is measured between the inside pegs. The test result is displayed in kilohm-centimeters (kΩ-cm). The distance between the pegs affects the results of the test.

PHOTO: LTRC

Surface resistivity test being conducted.

Problem

The Bridge Design Section of the Louisiana Department of Transportation and Development (DOTD) is transitioning statewide to load and resistance factor design (LRFD) for reinforced concrete structures. This change in design procedures requires testing more samples for permeability to ensure adequate protection against corrosion. The personnel hours for subjecting these samples to the rapid chloride permeability test, as required, were estimated in the tens of thousands per year.

Solution

The Louisiana Transportation Research Center (LTRC) therefore investigated the use of a surface resistivity device for the quality assurance and acceptance of structural concrete. The surface resistivity meter is user friendly. Louisiana DOTD conducted the research to expand on the results obtained in Florida for the surface resistivity meter at very high and very low w/cm ratios. The surface resistivity device provided a cost-effective alternative to the rapid chloride permeability test and assisted the department in the transition to LRFD.

The surface resistivity device was evaluated on concrete produced in the laboratory and in the field. The peg distance was fixed at 1.5 in. (3.81 cm) for all samples.

Concrete samples were produced in the laboratory from five mixtures at three different w/cm ratios (0.35, 0.50, and 0.65) to gain a range of permeability values. The mixtures were tested for surface resistivity and for rapid chloride permeability at 14, 28, and 56 days.

Field-cast specimens from the Twin Spans and Caminada Bay Bridge projects also were tested for surface resistivity and rapid chloride permeability at 28 and 56 days. In addition, laboratory samples from an ongoing study of ternary cementitious combinations—with up to 90 percent SCM content—were tested at 28 and 56 days. The study tested approximately 150 unique mixtures.

The LTRC laboratory's surface resistivity measurements correlated well (R^2 = 0.87) with rapid chloride permeability measurements across a wide range of permeability values, sample testing ages, and concrete mix designs (Figure 1, page 47). The regression equation in Figure 1 expresses the correlation between the 28-day surface resistivity (x) and the 56-day rapid chloride permeability (y).

The American Association of State Highway and Transportation Officials (AASHTO) recommends correlation with the ranges shown in Table 1 (page 47), delineating classes of chloride penetrability. Suitable correlations were found between the 14-day and 28-day surface resistivity values and the 56-day rapid chloride permeability values.

The 28-day to 56-day correlation was implemented, to eliminate the need for a set of acceptance samples produced in the field. The surface resistivity test is conducted on cast samples, and the same samples then were tested for compressive strength.

The surface resistivity meter identified differences in w/cm ratios. Researchers at LTRC developed a precision statement using eight mixtures—two sets of three samples for each mixture—and 17 operators. The single operator coefficient of variation (COV) of a single test result was 2.2 percent, and the multi-laboratory COV of a single test result was 3.9 percent.

With the results from this study, Louisiana DOTD developed the Test Method for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration (DOTD TR 233-11). A specification was prepared to incorporate the surface resistivity test into Louisiana DOTD's standards and specifications.

Application

Louisiana DOTD published the new specification in 2012 but already had changed its permeability testing procedures for quality assurance to reflect the new specification. The department developed and implemented a statewide training program on the proper use of the surface resistivity meter.

The surface resistivity meter has been used to accept the concrete placed for the LA-1, Caminada Bay, and Twin Spans Bridge projects. Concrete for the Twin Spans and Caminada Bay Bridge projects was accepted from compressive strength results and from surface resistivity results. The surface resistivity results, sampled from every lot and tested at 28 days, were compared with the classes shown in Table 1; all three projects met the classification of very low permeability.

Benefits

Every year, Louisiana DOTD tests an average of 480 lots for quality assurance on projects constructed within the state. As the new permeability specifications are implemented statewide, this number is expected to increase by several orders of magnitude.

The ASTM C1202 test equipment costs $18,000, and the surface resistivity meter costs $2,800. The complete ASTM C1202 testing requires 8.0 personnel hours; in contrast, the surface resistivity test requires 0.33 personnel hour.

TABLE 1 Louisiana DOTD Surface Resistivity and Permeability Classes for 4-x-8-in. Cylinders

Permeability Class	56-Day Rapid Chloride Permeability Charge Passed (coulombs)	28-Day Surface Resistivity (kΩ-cm)
High	>4,000	<12
Moderate	2,000–4,000	12–21
Low	1,000–2,000	21–37
Very Low	100–1,000	37–254
Negligible	<100	>254

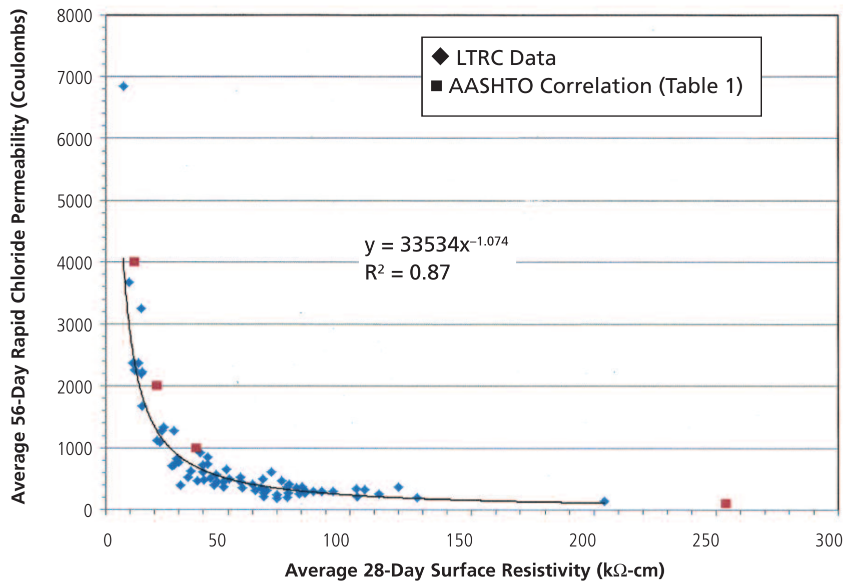

FIGURE 1 Relationship between the average 28-day surface resistivity test results and the average 56-day rapid chloride permeability test results.

The savings in technician costs in the first year can pay for 10 additional resistivity meters for the district laboratories and the central materials laboratory. The preliminary cost–benefit analysis shows that implementing surface resistivity measurements in lieu of rapid chloride permeability tests can save Louisiana DOTD approximately $101,000 in personnel costs for testing 480 lots in the first year.

The cost savings associated with contractor quality control testing are even greater. Contractors send approximately 3,000 ASTM C1202 samples to an independent laboratory for testing at a cost of $500 per sample—for the testing only. The estimated cost savings of $1.5 million to the contractors should indirectly benefit the department.

The estimated combined savings for Louisiana DOTD in the first year of implementation total about $1.6 million. The research project cost $103,000—a cost–benefit ratio of more than 15. The preliminary analysis shows that the department can save a significant amount of money by switching to the newer, faster surface resistivity test method.

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Resources

Technical Report: www.ltrc.lsu.edu/pdf/2011/fr_479.pdf.

Test Method: www.dotd.la.gov/highways/construction/lab/testproc/tr_233_final.pdf.

Training Video: www.ltrc.lsu.edu/videotraining/Resistivity/Resistivity.swf.

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Suggestions for Research Pays Off topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (202-334-2952; gjayaprakash@nas.edu).